Published in final edited form as:
J Clin Exp Neuropsychol. 2010 April ; 32(4): 417–432.

Language disorders in children with central nervous system injury

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Abstract

Children with injury to the central nervous system (CNS) exhibit a variety of language disorders that have been described by members of different disciplines, in different journals, using different descriptors and taxonomies. This paper is an overview of language deficits in children with CNS injury, whether congenital or acquired after a period of normal development. It first reviews the principal CNS conditions associated with language disorders in childhood. It then describes a functional taxonomy of language, with examples of the phenomenology and neurobiology of clinical deficits in children with CNS insults. Finally, it attempts to situate language in the broader realm of cognition and in current theoretical accounts of embodied cognition.

Keywords

Language disorders; Pragmatic; Semantic; Syntactic; Motor speech; Central nervous system injury

INTRODUCTION

Children and adolescents identified with injury to the central nervous system (CNS) exhibit a variety of language disorders that have been described by members of different disciplines, in different journals, using different descriptors and taxonomies. This paper is an overview of language deficits in children with CNS insults, whether congenital or acquired after a period of normal development. It first reviews the principal CNS conditions associated with language disorders in childhood. It then describes a functional taxonomy of language, with examples of the phenomenology and neurobiology of clinical deficits in children with CNS insults. Finally, it attempts to situate language in the broader realm of cognition and in current theoretical accounts of embodied cognition.

The scope of the paper is limited to language after CNS injury. It does not cover primary language acquisition failure (specific language impairment, SLI), language in conditions defined by abnormal behavior (e.g., autism; attention deficit hyperactivity disorder, ADHD), language associated with basic sensory loss (e.g., deafness), or language in children with mental retardation of genetic origin (e.g., Down syndrome, Fragile X syndrome, Williams–Beuren syndrome). Although these conditions are often correlated with abnormal brain development, they are not identified by CNS injury, and their language characteristics and intervention issues have been covered extensively in journal articles and in recent handbooks (e.g., Fletcher & Miller, 2005; Schwartz, 2008).

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CONDITIONS ASSOCIATED WITH CHILDHOOD LANGUAGE DISORDERS

In children, language can be disrupted by congenital malformations originating at various points during gestation, by birth trauma, or by brain injury acquired at a later point in development. The broadest distinction is that between congenital and acquired language disorders.

Congenital conditions

Unlike adults, children may be born with a significant compromise of the brain mechanisms responsible for language. A large number of congenital conditions affect language.

Spina bifida meningomyelocele—Spina bifida meningomyelocele (SBM) is a neural tube defect associated with malformations of spine and brain. It occurs at a rate of 0.3–0.5 per 1,000 live births (from postdietary fortification data), a decline over the past 20 years widely attributed to the emphasis on dietary supplementations of folate acid and vitamin B (Williams, Rasmussen, Flores, Kirby, & Edmonds, 2005).

The neurobiology of SBM involves structural and microstructural abnormalities of the cerebellum, midbrain, and posterior cortex; and hypoplasia and microstructural abnormalities of white matter tracts, including the corpus callosum (Del Bigio, 1993; Dennis et al., 1981; Dennis et al., 2005; Fletcher et al., 1996; Fletcher et al., 2005; Fletcher, Dennis, & Northrup, 2000; Hannay, 2000; Hasan et al., 2008).

Inborn errors of metabolism—Systemic metabolic disorders that result in the accumulation of metabolites in the bloodstream cause brain disruption that may include speech and language deficits. Some of the inborn errors of metabolism that have been shown to affect speech and language include phenylketonuria (an absence of the enzyme phenylalanine), galactosemia (an inability to utilize the sugars galactose and lactose because of disordered carbohydrate metabolism), Wilson disease (a progressive degenerative disorder of the brain and liver resulting from inability to process dietary copper), Sanfilippo syndrome (an autosomal recessive enzyme deficiency; Valstar, Ruijter, van Diggelen, Poorthuis, & Wijburg, 2008), and congenital hypothyroidism (Ozanne, Murdoch, & Krimmer, 1990).

Unilateral congenital pathology—Because of the common association of adult language disorders with left hemisphere brain insult, children with congenital damage to one side of the brain are of interest to theories of language development, language lateralization, and functional age-based plasticity. Although much theoretically interesting information about language has emerged from the study of early focal lesions (e.g., Bates, Thal, & Janowsky, 1992; Bates, Vicari, & Trauner, 1999), children with complete removal of one hemisphere have been of particular interest: They represent an extreme form of unilateral brain injury; cases have similar volumes of lateralized brain damage; and the congenital malformations in some series are identical on left and right sides (e.g., Hoffman, Hendrick, Dennis, & Armstrong, 1979), allowing exploration of differences in laterality unconfounded by differences in pathology.

Childhood-acquired conditions

Like adults, children can exhibit language disorders from injury to the central nervous system after a period of normal development. Childhood-acquired language disorder, or childhood-acquired aphasia, refers to language impairment evident after a period of normal language acquisition that is precipitated by, or associated with, an identified form of brain insult.

Seizure disorders—Seizure disorders may be associated with language deficits (Williams & Sharp, 2000), and language symptoms may be part of clinical seizures or part of ictal speech automatisms. The most studied seizure disorder is the Landau–Kleffner syndrome (Denes, 2008; Landau & Kleffner, 1957), which involves acquired aphasia with convulsive disorder and agnosia for sounds in children who acutely or progressively lose previously acquired language (Appleton, 1995; Majerus, Van der Linden, Poncelet, & Metz-Lutz, 2004).

Vascular disorders—Vascular disorders involve interruptions to the blood supply within the brain as a result of occlusion (ischemic stroke) or rupture (hemorrhagic stroke). Degenerative disorders like atherosclerosis are rare in children, while vascular strokes associated with congenital heart disease occur in childhood (Ozanne & Murdoch, 1990), from an embolism from the heart, complications of heart surgery, or hypoperfusion from prolonged hypotension, or from sickle cell disease (Ris & Grueneich, 2000). The neurobiology of childhood strokes is variable. Many childhood strokes are secondary to intracranial occlusive disease in the basal ganglia, although cortical vascular lesions in the left temporoparietal lobe that produce aphasia occur from cerebral arteritis (Dennis, 1980b) or ruptured arteriovenous malformations (Hynd, Leathem, Semrud-Clikeman, Hern, & Wenner, 1995).

Traumatic brain injury—Children exhibit a range of language disturbances in the acute phase after head injury (Guttmann, 1942; Jordan, 1990; Loonen & Van Dongen, 1990; Van Dongen & Loonen, 1977), a common cause of childhood-acquired language disorders. The neurobiology of childhood traumatic brain injury (TBI) includes immediate impact injury (contusions, diffuse axonal damage), secondary intracranial events (hematomas, brain swelling, infections, subarachnoid hemorrhages, hydrocephalus), and extracranial factors (hypoxia, hypotension). TBI results in focal brain damage (vascular injury involving contusions and hemorrhage, especially in the frontal and temporal lobes) and diffuse brain damage (to axons in the white matter), as well as in secondary damage such as raised intracranial pressure, hypoxia, and ischemia (Gennarelli & Graham, 1998).

Brain tumors—Brain tumors in children are often associated with language disturbances (Hudson, 1990; Van Dongen & Paquier, 1991). The neurobiology of brain tumors depends on the tumor etiology, size, and location. The most studied form of childhood brain tumors are posterior fossa tumors, such as malignant medulloblastomas and benign astrocytomas, which occur with relatively high frequency in children, and which are associated with speech and language deficits (Dennis, Spiegler, Riva, & MacGregor, 2004).

Cancer treatments—Radiotherapy and chemotherapy, which are often part of the treatment for childhood cancers such as acute lymphoblastic leukemia or malignant brain tumors, cause structural and functional damage to the brain (Withers, 1992). Long-term survivors of acute lymphoblastic leukemia treated with radiation and chemotherapy show cognitive deficits that include language impairments (Hudson, Buttsworth, & Murdoch, 1990; Moleski, 2000).

Infectious conditions—Infectious diseases of the brain, which may involve viral, bacterial, spirochetal, and other microorganisms that infect the meninges or the brain, may affect language (Anderson & Taylor, 2000; Smyth, Ozanne, & Woodhouse, 1990), either as a primary effect of brain involvement in conditions like herpes simplex encephalitis, or as a secondary effect of sensorineural hearing loss in conditions such as bacterial meningitis or toxoplasmosis.

Hypoxic disorders—Anoxia, a state in which the oxygen levels in the body fall below physiologic levels because of depleted oxygen supply, can come about from various causes (including severe hypotension, cardiac arrest, carbon monoxide poisoning, near-drowning, and suffocation) that involve a drop in the level of cerebral blood flow or the oxygen content of the blood. A prolonged period of cerebral anoxia will produce permanent brain damage or anoxic encephalopathy, which is associated with a range of language deficits (Murdoch & Ozanne, 1990).

LANGUAGE DISORDERS

Broadly, language is a code that links linguistic representations with various levels of meaning (Caplan, 1992): of words, sentences, texts, and social–affective communication. The code can be instantiated in different modalities (auditory, visual, tactile) and described at different levels of analysis (word, sentence, text). Multiple codes may coexist.

This section reviews the characteristics of language disorders associated with congenital brain defects or acquired brain conditions. The information is organized in a taxonomy (Figure 1) that (reading from left to right) shows language representation level, functional domain, example of functional domain, and representative clinical deficit.

Pragmatics

Pragmatics is concerned with how speakers use language to effect successful functional communication (Kempson, 1975). Pragmatic linguistic representations are activated, typically in social contexts, to serve intentional purposes (e.g., to give instructions, to mask and/or communicate thought), and to make affective judgments (e.g., to praise, blame, criticize, or empathize). A key issue in pragmatic comprehension, as Stemmer (2008) suggests, is how to compute meaning from something that is not stated, a task that requires distinguishing sentence meaning (the semantic properties of a sentence) and speaker meaning (what the speaker intended to communicate; Noveck & Reboul, 2008).

Intentions—As originally used (Brentano, 1874/1973), intentionality referred to a property of mental states: that of being directed towards something. More recently, intentionality is used as a form of representation for mental categories such as beliefs and desires (Malle, Moses, & Baldwin, 2001), with intentionality being a quality of purposeful actions, and intentions being mental states that represent those actions. Theory of mind, a component of social cognition (Yeates et al., 2007), involves the ability to think about mental states in oneself and others and to use them to understand and predict what other people know and how they will act (Bibby & McDonald, 2005). The term, theory of mind, emphasizes that individuals see themselves and others in terms of mental states—desires, emotions, beliefs, intentions, and other inner experiences—that result in (and from) human action (Wellman, Cross, & Watson, 2001).

The primary meaning of some verbs is not an action but an internal state. Mental state verbs (Hall & Nagy, 1986) are a class of words that include *know, remember, forget, think, believe*, and *pretend* (Hall & Nagy, 1986; Karttunen, 1971). These words assume some information (presuppositions) and suggest other information (implications; Karttunen, 1971; Kiparsky & Kiparsky, 1970). Speech acts (Searle, 1969) are intentional acts performed by a dialogue participant to express the mutual intentions of a speaker and a listener and to influence the mental state of a participant (Beun, 1994).

Children with TBI have deficits in comprehension of mental state verbs (Dennis & Barnes, 2000) and in producing appropriate speech acts (e.g., when asked to produce a statement using the words "*pie either have*" while looking at a picture of adolescents in a school cafeteria staring at a selection of desserts; Dennis & Barnes, 2000). Adolescents with TBI who perform poorly on a test of theory of mind express few mental state terms in their conversations (Stronach & Turkstra, 2008). Children with early unilateral brain damage have impairments in making pragmatic inferences, with different profiles of deficit occurring depending on lesion laterality (Eisele, Lust, & Aram, 1998).

Affect—Pragmatics concerns feelings and judgments, as well as information. The ability to be emotionally deceptive is an important component of pragmatics because it requires the recognition that inner emotional states need not be congruent with emotional expressions (Saarni, 1999). Expressing experienced emotion has been termed *emotional expression*, in contrast to communicating a socially appropriate emotion, *emotive communication* (Buck, 1994).

Children with TBI have more difficulty with emotive than with emotional communication. They can identify basic emotions felt by characters in narratives (e.g., they know that a character will feel sad when she is sick), and they can understand why a deceptive emotion might be communicated (e.g., they know that a child's mother will not allow her to play if aware that she is sick); nevertheless, they are unable to communicate the socially deceptive emotion (e.g., looking happy; Dennis, Barnes, Wilkinson, & Humphreys, 1998). When performing the same task, children with autism, a profound disorder of language and communication, have deficits in both emotional and emotive communication (Dennis, Lockyer, & Lazenby, 2000).

Intentional–affective language—Intentions and affect often operate together, as in irony and empathy. Irony has complex social functions. Through the use of the rhetorical functions of praise and blame, irony conveys social messages that include formulating a judgment while muting its evaluative force (Dews & Winner, 1997), muting criticism (Harris & Pexman, 2003), or establishing social distance through a negative assessment of the actions of the hearer (Haverkate, 1990). Empathy is a means of giving comfort or maintaining social connectedness in complex or difficult situations. One might use an empathic lie, for instance, to make someone feel better about a bad haircut (e.g., "Your hair looks really nice like that!").

Children with TBI have difficulty understanding irony and empathy. They do not distinguish between the second-order intentions of irony (to make the hearer feel bad about himself or herself) and empathy (to make the hearer feel good about himself or herself; Dennis, Purvis, Barnes, Wilkinson, & Winner, 2001).

Syntax

Syntactic structures assign important aspects of sentence meaning (Caplan & Hildebrandt, 1988), especially of functional roles (e.g., who is acting, who is being acted on). Failure to assign and interpret syntactic structure signals a syntactic comprehension disorder (Caramazza & Zurif, 1976), the hallmark of which is an inability to assign aspects of sentence meaning correctly in sentences that are logically and pragmatically semantically reversible except for syntactic structure (e.g., the dog chased the cat/the cat chased the dog). Of patients with syntactic comprehension deficits, some are able to construct relevant syntactic structures even when they fail to map the products to establish meaning (e.g., Linebarger, 1990).

Syntactic arguments—The adult neurobiology of syntax suggests left lateralization. The adult left hemisphere has a strong association with syntax; functionally, it constructs syntax in real time (Swinney, Zurif, Prather, & Love, 1996) and assigns syntactic structure during language comprehension (Caplan, 1992; Caplan & Hildebrandt, 1988; Stromswold, Caplan, Alpert, & Rauch, 1996). Damage to perisylvian areas of the left hemisphere disrupts syntax; conversely, left hemisphere damage that spares this region and disrupts lexical–semantic function preserves sensitivity to syntax (Dogil, Haider, Husmann, & Schaner-Wolles, 1995).

The immature left hemisphere also has a strong association with syntax. Compared to those with early right hemisphere damage and hemispherectomy, individuals with congenital damage to and removal of the left hemisphere are slower and less accurate in understanding sentences with noncanonical word orders (e.g., reversible passive sentences such as *the dog is chased by the cat*) in which meaning is provided by syntactic structure but not semantic plausibility, whether comparisons are made between hemidecorticate groups with early lateralized hemispheric damage from varying pathologies (Dennis & Kohn, 1975) or from a single pathology (Dennis & Whitaker, 1976). The syntactic comprehension deficit after left hemisphere damage is evident whether comparisons are made to chronological age (Aram, Ekelman, Rose, & Whitaker, 1985; Dennis, 1980a; Dennis & Kohn, 1975; Dennis & Whitaker, 1976; Paquier & Van Dongen, 1993), mental age (Stark, Bleile, Brandt, Freeman, & Vining, 1995), or brain-intact cotwins (Feldman, Holland, & Keefe, 1989; Hetherington & Dennis, 2004).

Syntactic comprehension deficits for noncanonical word orders are also evident when only part of the left hemisphere is removed but speech control has shifted to the right hemisphere (Kohn, 1980). These data are in agreement with functional magnetic resonance imaging (fMRI) demonstrations that language reorganization after hemispherectomy in childhood involves right hemisphere homologues of the left hemisphere language areas (Liégeois, Connelly, Baldeweg, & Vargha-Khadem, 2008) and also with data showing that congenital left hemisphere focal lesions prompt a mirror-image reorganization of the entire cerebrocerebellar network engaged in speech production (Lidzba, Wilke, Staudt, Krägeloh-Mann, & Grodd, 2008).

Semantics

Broadly, semantics is concerned with meaning. Semantic disorders in children with brain injury range from severe verbal auditory agnosia for common sounds, such as a dog barking or a doorbell ringing (Cooper & Ferry, 1978), to problems understanding word meaning (Dennis, 1992) or oral or written texts (Barnes, Faulkner, Wilkinson, & Dennis, 2004).

Lexicon—The lexicon consists of a word store, most of it concerned with literal meanings of individual words. The lexicon also involves phrasally stipulated meanings of overlearned figurative expressions, such as common idioms.

Literal meaning: According to standard models of speech production (Levelt, 1989), producing semantically appropriate words requires accessing word forms as well as word–sound planning so that the representation of the sound of a word may be converted into a form suitable for production. Disorders of lexis are common in both adults (Libben, 2008) and children with brain injury.

Impairments in accessing word forms from concepts are exhibited by failure to produce a word in response to a picture, definition, or context, despite intact semantic and phonological processing evidenced by the ability to describe, categorize, or repeat the target word. A variety of forms of childhood brain injury are associated with word-finding difficulties in which children can produce a word in response to a picture, although not to semantic information such as “What lives in the jungle, has big floppy ears and a trunk?” (Dennis, 1992). Indications of a disorder in accessing word forms include pauses, sequences of sounds that do not form words (neologisms), words related in meaning to the target (semantic paraphasias), and the use of circumlocutions. In the fluent form of childhood aphasia, associated with lesions to the posterior left hemisphere cortical language areas (Klein, Masur, Farber, Shinnar, & Rapin, 1992), anomia, word-finding deficits, semantic paraphasias, and circumlocutions occur (Dennis, 1980b; Hynd et al., 1995). Children with aphasia from TBI exhibit a variety of language symptoms in the acute stage, which show some resolution over time (Loonen & Van Dongen, 1990; Van Dongen & Loonen, 1977), even though anomia and reduced verbal fluency are consistent long-term deficits (Hécaen, 1983; Jordan & Murdoch, 1993; Jordan, Ozanne, & Murdoch, 1988, 1990).

The adult aphasia literature includes an extensive series of report of category-specific semantic disorders, with reports of selective semantic impairment of particular concepts, such as those related to animate things and food compared to man-made objects (e.g., Sartori & Job, 1988). Interpretation of category-specific naming deficits is still controversial (see Mahon & Caramazza, 2009; Martin & Caramazza, 2003).

Modality-specific anomia has been described in children (e.g., Dennis, 1976). Reading and spelling may be relatively preserved with cortical lesions in the left-hemispheric posterior language areas in children with anomia (Dennis, 1980b; Hynd et al., 1995). Further, a child with anomia from stroke was able to perform tactile–visual matches of misnamed objects (Dennis, 1980b). These data suggest a problem between modality-specific semantic systems and the activation of auditory word forms.

Literal meaning has been studied by analysis of symptoms of fluent adult aphasia, such as logorrhea, verbal stereotypies, perseverations, neologisms, jargon, and paraphasias, which were once thought to be rare in children (Alajouanine & Lhermitte, 1965). Aphasic symptoms in children have proved to be quite varied (Van Hout, 1991), with a number of adult aphasic syndromes being described in children: jargon aphasia (Visch-Brink & Van de Sandt-Koenderman, 1984; Woods & Teuber, 1978); Wernicke's aphasia and transcortical sensory aphasia (Van Hout, Evrard, & Lyon, 1985); conduction aphasia (Van Dongen, Loonen, & Van Dongen, 1985); transcortical sensory aphasia (Cranberg, Filley, Hart, & Alexander, 1987; Van Dongen & Paquier, 1991); anomic aphasia (Hynd, Semrud-Clikeman, Lorys, Novey, & Eliopulos, 1990); and alexia without agraphia (Makino et al., 1988; Paquier et al., 1989). To be sure, adult aphasic syndromes observed in children occur with different base frequencies (Rapin, 1995).

Figurative meaning: Idioms are nonliteral phrases (e.g., *kick the bucket*) whose figurative meanings (here, *to die*) cannot be derived from the literal meanings of their individual words (here, *kick* and *bucket*). Idioms are ubiquitous (Brinton, Fujiki, & Mackey, 1985) in conversational (approximately four figures of speech occur in each minute of conversation; Pollio, Barlow, Fine, & Pollio, 1977) and instructional language (Lazar, Warr-Leeper, Nicholson, & Johnson, 1989).

Studies of figurative language have identified two types of idiom: one processed like literal language, the other requiring semantic decomposition. Nondecomposable idioms (e.g., *kick the bucket*) are learned and represented in the mental lexicon as units; being syntactically and lexically inflexible, they depend on context for interpretation (Gibbs, 1991). Children with SBM have difficulty understanding idioms, even when they can understand the individual words in the idiom. Of interest, they are better able to understand idioms whose meaning can be derived from the individual words (e.g., "talk a mile a minute") than nondecomposable idioms that require them to integrate the words and the context (Huber-Okrainec, Blaser, & Dennis, 2005). Their relatively well-preserved syntax and grammar skills for literal language (Dennis, Hendrick, Hoffman, & Humphreys, 1987) may facilitate the semantic compositional analysis of decomposable, but not nondecomposable, idioms.

The neurobiology of idioms may involve a distributed neural system. For children with SBM, variability in idiom comprehension is related to the integrity of the corpus callosum (Huber-Okrainec et al., 2005).

Text—The derivation of meaning in oral or written texts involves complex (van Dijk & Kintsch, 1983) inferencing and integration among a text representation built on current words and sentences, prior context, and world knowledge (Perfetti & Frishkoff, 2008). The flow of topics, narrative script, and the plotline form the schematic structure. The text macrostructure concerns the relations among sentences sharing a topic, and deficits in macrostructure are usually manifest as failures of text coherence. Text microstructure concerns local sentential relations, and these are usually manifest as failure of text cohesion.

Schematic structure: Problems in schematic structure are not uncommon in children with brain injury. Both children with TBI and children with hydrocephalus, most with SBM, have deficits in producing and understanding social scripts (Chapman et al., 1992; Dennis & Barnes, 1990).

Macrostructure and microstructure: Problems in text macrostructure are also common in children with brain injury. In telling stories, children with hydrocephalus, most with SBM, produce poorly coherent narratives that are difficult to process, unclear, and uneconomic (Dennis, Jacennik, & Barnes, 1994). Children with TBI also have problems in discourse macrostructure (Chapman et al., 2004; Ewing-Cobbs, Brookshire, Scott, & Fletcher, 1998).

Problems in text microstructure have been identified in children with CNS injury. Children with left hemi-decortication for congenital left hemisphere damage have impaired referential cohesion in texts, failing to sustain a chain of anaphoric reference (Lovett, Dennis, & Newman, 1986). Children with early focal brain injury also show impairments in referential cohesion (Reilly, Bates, & Marchman, 1998). Compared to controls, the narratives of children with hydrocephalus, most with SBM, include referentially ambiguous material (Dennis et al., 1994).

Inferencing—Text meaning is constructed over time, not always literally stated. Text inferences create a text representation, through coherence inferences (integration of semantic knowledge with lexical content to interpret the text) and elaborative inferences (creation of a mental model of the situation the text describes; Morrow, Bower, & Greenspan, 1990; Whitney, 1987; Zwaan, Langston, & Graesser, 1995). Children with TBI make coherence but not elaborative inferences (Barnes & Dennis, 2001; Dennis & Barnes, 2001).

Text inferences: Text-based representations denote the literal meaning of the text and are constructed through integration of information in the text and revision of information in relation to the unfolding context (Clifton & Duffy, 2001; Kintsch, 1988; Schmalhofer, McDaniel, & Keefe, 2002). Integration is effected through processes such as pronominal reference, which links characters, objects, and events with their referent pronouns, and by bridging inferences, which integrate ideas or sentences explicitly stated within a text.

Initially, word meanings are passively activated without respect to the context; typically, more semantic information is activated than will be required to represent the text (Schmalhofer et al., 2002). As text becomes integrated, contextually irrelevant meanings are suppressed or their activation is not sustained, and appropriate meanings are enhanced (Gernsbacher, 1990; Gernsbacher & Faust, 1991). For example, in order to interpret the sentence, “Jim picked up the spade,” the reader may retrieve information from earlier in the text about Jim helping his mother in the garden. Children and adolescents with hydrocephalus, most with SBM, have difficulty integrating propositions within texts, take longer to integrate information over larger chunks of text, continue to show substantial interference effects in ambiguity resolution tasks beyond the point at which their peers have suppressed contextually irrelevant meanings, and are less efficient in constructing a coherent and integrated text base (Barnes et al., 2004).

Knowledge-based inferences: The online working model of text meaning includes real-world knowledge and goals, such as inferences about space, time, causality, and the goals of the characters (Kintsch, 1988; Schmalhofer et al., 2002; Zwaan & Radvansky, 1998). Constructing situation models requires knowledge-based inferences, which we have studied in typical (Barnes, Dennis, & Haefele-Kalvaitis, 1996) and atypical (Barnes & Dennis, 1996, 2001; Cain, Oakhill, Barnes, & Bryant, 2001) development, using a paradigm in which children learn a new knowledge base about a make-believe world and then integrate new knowledge with events in the text. Children with hydrocephalus, most with SBM, make fewer knowledge-based inferences than controls (Barnes & Dennis, 1998). Differences with same-age peers are magnified when the processing load is high (i.e., when inferences have to be made by retrieving knowledge from memory as stories unfold in time), and the differences are attenuated when the processing load is low (i.e., when they are cued with the knowledge needed to make an inference; e.g., Barnes & Dennis, 2001; Cain et al., 2001).

Text-based comprehension—Text meaning is continuously and actively constructed through a series of online comprehension processes that operate at the word, sentence, and text levels, and which draw on cognitive resources such as working memory. In a recent model of meaning comprehension (Barnes, Huber, Johnson, & Dennis, 2007) we have proposed that meaning involves a surface code, a text base, and a situation model, the last two supported by an integration and revision buffer fueled by WM and inhibitory control. The surface code directly activates old meanings stored in memory. Online iterative cycles of integration and revision facilitate the construction of new meaning.

Models of comprehension distinguish between automatic activation of surface codes (the passive activation of meaning from stored lexical representations; Clifton & Duffy, 2001) and resource-intensive construction and revision of text-based representations and situation models. Children with SBM can construct text-based representations when the demands on integration and revision are relatively low, but not when significant revision processes are required. They seem unable to integrate across sentences to update and revise situation models. They also have difficulty constructing situation models by integrating text and world knowledge to understand ongoing narratives.

Phonology

The segmental aspect of phonology and speech processing involves phonological perception and integration (Plante, Holland, & Schmithorst, 2006) of features such as vowels, consonants, and syllables that have direct, identifying relationships with utterances (Crystal, 1973). The nonsegmental aspect of phonology concerns a range of features, loosely referred to as “tone of voice,” that include intonation, stress, rhythm, and speed of speaking and that have a variable relation to the segmental, verbal aspects of utterances (Crystal, 1973).

Segmentals—Disorders of phonological processing commonly follow both adult (Buckingham & Christman, 2008) and child brain injury (Aram & Nation, 1982). Impairments in word–sound planning are demonstrated by substitutions involving phonemes with dissimilar distinctive features and/or omissions and misordering of phonemes (phonemic paraphasias). Brain-injured children’s word-finding errors include phonemic paraphasias, phonemic jargon, and neologisms (Dennis, 1980b; Van Dongen & Paquier, 1991; Visch-Brink & Van de Sandt-Koenderman, 1984). Phonological-processing deficits are among the language and reading impairments reported in children who have sustained left hemisphere strokes in middle childhood (Dennis, 1980b; Pitchford, 2000). Compared to his cotwin, a child with a left hemisphere stroke in middle childhood regained phonological skills lost at the time of the stroke, although he failed to acquire new phonological skills (Hetherington & Dennis, 2004).

Phonological compromise is often considered the core deficit in developmental dyslexia (Lyon, 1995). Structural and functional neuroimaging studies of normal readers and individuals with dyslexia have demonstrated the engagement of left hemisphere structures in both reading and phonological processing (e.g., Pugh et al., 2000; Simos, Breier, Fletcher, Bergman, & Papanicolaou, 2000).

Suprasegmentals—Prosody, or suprasegmental information, cues both emotional state (emotional prosody, including the emotional state of the speaker) and language structure, including sentence type (e.g., whether question or statement), the occurrence of phrasal units within sentences, and boundaries or words within phrases (Plante et al., 2006). Disturbances in emotional prosody have been observed in adults with brain injury (Van Lancker-Sidtis, 2008) and in children with severe TBI (Hattiangadi et al., 2005). In terms of neurobiology, prosodic disturbances have been observed in children with right hemisphere dysfunction (Cohen, Branch, & Hynd, 1994) and young adults with congenital agenesis of the corpus callosum (Paul, Van Lancker-Sidtis, Schieffer, Dietrich, & Brown, 2003).

Morphology

Morphology is critical to the production of complex words (Jarema, 2008), and components of the language production system are important for producing free-standing function words and inflectional morphemes in words and sentences. These morphological components are different from vocabulary words because they do not bear nonemphatic stress in derived words or sentence structures, and they do not follow regular word formation processes. The speech of adult aphasic patients with anterior lesions is often agrammatic, with a breakdown of sentence structure and the omission or misuse of grammatical morphemes, even while access to content words, such as verbs and nouns, is relatively unimpaired. In adults, a disturbance affecting the production of inflections and derivational morphemes has been termed *agrammatism* or *paragrammatism*, and the characteristic is the omission or substitution of function words and affixes (Menn, Obler, & Goodglass, 1990).

The neurobiology of morphology suggests some hemispheric lateralization in some cases of childhood CNS damage. Curtiss and Schaeffer (1997) analyzed the language of children with hemispherectomy with respect to the inflectional (I) system and its subcategories tense, subject agreement, and object agreement. Compared to those with right hemispherectomy, children with left hemispherectomy use a restricted range and number of I-system morphemes and have particular problem with auxiliaries, despite intact syntactic and morphological structures of other types (Curtiss & Schaeffer, 1997). Children with left hemispherectomy also have particular problems producing tag questions, which involve inflectional morphology (Dennis & Whitaker, 1976), and deficits that occur in some adults with paragrammatism. These data suggest a high level of vulnerability of the inflectional system to developmental, childhood-acquired, and adult-acquired language pathology.

Speech production

Phonetics—Phonetic deficits, termed *developmental apraxia of speech* or *developmental verbal dyspraxia*, involve difficulty in coordinating voluntary movements of the speech articulation mechanism (Aram & Nation, 1982; Shriberg, Aram, & Kwiatkowski, 1997a, 1997b). They are a neurological childhood speech sound disorder in which the precision and consistency of speech movements are impaired in the absence of neuromuscular deficits such as abnormal reflexes. They may occur from known neurological impairment or as an idiopathic speech sound disorder, and the core impairment is in planning and/or programming the spatiotemporal parameters of movement sequences that result in errors of speech sound production and speech prosody (American Speech-Language-Hearing Association, 2007). They may co-occur with language disorders and/or speech fluency disorders, described below.

Motor speech—Congenital malformations of the cerebellum are associated with a form of ataxic dysarthria, which is a motor speech deficit involving dysfluency, ataxic dysarthria (articulatory inaccuracy, prosodic excess, and phonatory–prosodic insufficiency), and slowed speech rate (Brown, Darley, & Aronson, 1970; Darley, Aronson, & Brown, 1969). The narratives of both children and young adults with SBM are characterized by all three motor speech deficits (Huber-Okrainec, Dennis, Brettschneider, & Spiegler, 2002).

A range of acquired CNS insults in children result in mutism, often resolving to ataxic dysarthria, and termed mutism with subsequent dysarthria (MSD). There is an initial period of mutism in herpes simplex encephalitis (Paquier & Van Dongen, 1991; Van Hout et al., 1985), and mutism has also been described in children treated for cancer (Hudson et al., 1990) and children with anoxic encephalopathy (Cooper & Flowers, 1987).

The most fully studied form of MSD is the one identified in children treated for posterior fossa tumors, who acutely or progressively lose previously acquired language skills (Dailey, McKhann, & Berger, 1995; Di Cataldo et al., 2001; Doxey, Bruce, Sklar, Swift, & Shapiro, 1999; Humphreys, 1989; Rekate, Grubb, Aram, Hahn, & Ratcheson, 1985; Van Dongen, Catsman-Berrevoets, & van Mourik, 1994). Nearly all MSD patients are less than 10 years of age, and the condition has been described in children as young as age 2 (Van Dongen et al., 1994).

The MSD syndrome involves a complete but transient loss of speech, resolving into a dysarthria with imprecise consonants, articulatory breakdowns, prolonged phonemes, prolonged intervals, slow rate of speech, lack of volume control, harsh voice, pitch breaks, variable pitch, and explosive onset (Hudson, Murdoch, & Ozanne, 1989; van Mourik, Catsman-Berrevoets, Yousef-Bak, Paquier, & Van Dongen, 1998). Improvement of the dysarthria to normal speech seems to be related to the recovery of complex movements of the mouth and tongue (Van Dongen et al., 1994).

Long-term recovery of the ataxic dysarthria is incomplete. Very-long-term survivors of childhood cerebellar tumors continue to show ataxic dysarthric features in their spontaneous speech (Huber, Dennis, Bradley, & Spiegler, 2007); further, tumor survivors with a history of MSD show more ataxic dysarthria than those without MSD at the time of tumor treatment (Huber-Okrainec, Dennis, Bradley, & Spiegler, 2006).

Because mutism has been most commonly associated with cerebellar tumors, its neurobiology has been fairly well studied. Mutism has been associated with posterior fossa tumors located in the midline or vermis of the cerebellum and with tumors that invade the cerebellar hemispheres or the deep nuclei of the cerebellum (Humphreys, 1989; Rekate et al., 1985) and brainstem (Doxey et al., 1999; van Mourik et al., 1998). Children with postoperative mutism show brainstem compression, which may represent white matter injury (McMillan et al., 2009). It has been proposed that the mutism of MSD is related to bilateral involvement of the dentate nuclei, and, further, that the subsequent dysarthric speech represents a recovering cerebellar mechanism (Ammirati, Mirzai, & Samii, 1989).

LANGUAGE AND OTHER COGNITIVE SYSTEMS

Language does not exist in isolation. Both comprehension and production of language are grounded in the motor system. Language is related to general-purpose brain memory systems and is instantiated by cognitive resources such as working memory and inhibitory control.

Language as embodied action

Earlier views of language assumed it to have conceptual content that was more abstract than information in sensory and motor systems. More recently, however, the embodied cognition framework has argued that conceptual content is grounded in basic sensory and motor processes (e.g., Gallese & Lakoff, 2005; Zwaan, 2004). Current theoretical accounts of language as embodied action (Fernandino & Iacoboni, in press; Fischer & Zwaan, 2008) are unraveling the interaction between the brain's systems of language and action for both production and comprehension (reviewed in Zwaan, Taylor, & de Boer, in press). For example, verbs describing actions activate areas of the motor cortex that are also active when the action is performed. Verbs referring to hand actions activate the hand area of the motor strip, verbs referring to leg actions the more dorsal leg area, and verbs denoting mouth actions the mouth area (Hauk, Johnsrude, & Pulvermüller, 2004; but see Kemmerer, Gonzalez Castillo, Talavage, Patterson, & Wiley, 2008, who found somatotopic activation for hand and leg verbs, but not for mouth verbs). Similar effects have been reported in neuroimaging studies of sentence comprehension (Aziz-Zadeh, Wilson, Rizzolatti, & Iacobini, 2006; Tettamanti et al., 2005). Consistent with this, behavioral evidence suggests motor involvement in language comprehension (e.g., lexical stimuli have been shown to momentarily affect hand aperture in a reaching-to-grasp task; Gentilucci & Gangitano, 1998; Glover, Rosenbaum, Graham, & Dixon, 2004). Similarly, hand–arm actions are influenced by sensibility judgments about sentences (e.g., Glenberg & Kaschak, 2002; Zwaan & Taylor, 2006).

General purpose systems

It has been proposed (Ullman, 2008; Ullman et al., 1997) that lexical information depends on declarative memory (specialized for arbitrary associations and grounded in temporal lobe structures) while grammar relies on procedural memory (specialized for rules and sequences and rooted in frontal and basal ganglia structures). The argument is that, given that word forms are like facts in being arbitrary, the declarative memory system may subserve words as well as facts and events, and, given that rules are like skills in requiring the coordination of procedures in real time, the procedural memory system may process grammatical rules as well as motor and perceptual skills. Support for this proposal has come from several sources.

Although there are different views about whether regular and irregular past tense forms of verbs are both computed by rules (Chomsky & Halle, 1968) or memory (MacWhinney & Leinbach, 1991), Ni et al. (2000) hypothesized that irregular past tense verb forms are memorized, while regular forms (verb stem +ed) are generated by a rule that comprises two operations: copying the stem and adding a suffix. Patients with impaired declarative memory (Alzheimer's disease) or lexical memory (posterior aphasia) were found to overgeneralize the past tense suffix and to have more difficulty converting irregular verbs to past tense forms than they did converting regular or novel verbs. Patients with procedural impairments and damage to the frontal-basal ganglia system (Parkinson's disease) or with agrammatism (anterior aphasia) showed the opposite pattern. In a fMRI paradigm, form errors (e.g., "Trees can grew") triggered increased activation in the left inferior frontal area (Broca's area), whereas meaning anomalies (e.g., "Trees can eat") resulted in superior temporal and middle and superior frontal activation (Ni et al., 2000).

The broad dissociation between form and procedural memory, on the one hand, and meaning and semantic memory, on the other, is evident in children with brain injury. Despite a range of cognitive and language problems in the semantic and pragmatic domains (Fletcher, Barnes, & Dennis, 2002), children with SBM have intact procedural learning and memory (Edelstein et al., 2004), as well as relatively intact ability to assign thematic roles in syntactic comprehension tasks (Dennis et al., 1987). This dissociation is also demonstrable after childhood-acquired brain injury. Comparing language recovery in 13-year-old identical twins, one of which had sustained a left hemisphere arteritic stroke at age 7 (Hetherington & Dennis, 2004), we reported that the twin with the stroke showed full recovery of semantic memory and word production, but had persisting impairments in tag question production and the ability to assign thematic roles in syntactic comprehension tasks. Considered together, a group of studies suggest an association between the procedural system and grammar and a dissociation between the procedural system and semantics within a form of congenital brain injury and, further, an association between recovery of semantic memory and word finding and a dissociation between recovery of semantic memory and the persistence of syntactic impairments in childhood-acquired stroke.

Processing resources

Language comprehension is constrained by processing resources. WM is the process by which information is temporarily activated in memory for rapid manipulation and retrieval. Inhibitory control is the ability to stop or modulate ongoing actions or to switch between competing representations. In adults, verbal WM capacity is related to language comprehension (Caplan & Waters, 2006), and, in children, WM efficiency is linked to a range of language, learning, and academic competencies (e.g., Bull & Scerif, 2001). Both WM and inhibitory control have a resource-limited capacity (Gazzaley, Cooney, McEvoy, Knight, & D'Esposito, 2005), so WM involves the activation of information, and inhibitory control keeps irrelevant information out of WM (Dempster, 1993; Engle, Conway, Tuholski, & Shisler, 1995; Harnishfeger & Bjorklund, 1994) through processes like suppression.

Working memory—Understanding sentences and texts is subject to capacity constraints, and text comprehension requires active memory for meaning construction (Clifton & Duffy, 2001; van den Broek, Young, Tzeng, & Linderholm, 1999). Because texts extend over time, with semantic representations being iteratively modified by reactivating old information and linking it with incoming information, working memory is a capacity component of many language comprehension models (e.g., Kintsch, 1988; van den Broek et al., 1999).

Capacity constraints limit comprehension in children with language disorders. Sentence and text comprehension is impaired in SBM (e.g., Dennis & Barnes, 1993), with comprehension deficits being driven, at least in part, by capacity limitations related to integrating meaning over longer text segments (Barnes et al., 2004). WM links semantic information and its source and integrates distant information across text segments, and WM limitations are associated with poor text comprehension.

WM is a source of syntactic comprehension disorder (Caplan & Hildebrandt, 1988). One source is a specific disturbance with functional argument structure and difficulties with noncanonical orders of sentence constituents, possibly because of defective representations or procedures for handling the traces of moved semantic roles in sentences like passives and object relatives with noncanonical word orders (Berndt, Mitchum, & Wayland, 1997). Another source is a reduction in the computational resources for syntactic comprehension (Caplan, Waters, DeDe, Michaud, & Reddy, 2007). For example, the poor formation of syntax in adult Broca's aphasia occurs not because of insufficient knowledge of syntactic dependencies, but because of failure of real-time implementation of these specific representations (Love, Swinney, Walenski, & Zurif, 2008).

Individuals with hemispherectomy for early left hemisphere injury have a combined impairment. They are insensitive to the role of function words that cue syntactic structure, even on metacognitive tasks with no time constraints (Dennis, 1980a), which suggests that they have trouble constructing functional argument structures. In addition, they are slower to respond correctly to noncanonical sentences, and they make fewer errors when they respond slowly (Dennis & Kohn, 1975), which suggests some limitation in WM resources, with performance deficits becoming attenuated when more WM resources are allocated to the task.

Inhibitory control: Activation and suppression—Inhibitory control may be automatic or effortful (Friedman & Miyake, 2004). Automatic inhibitory control, such as the ability to avoid returning gaze to a previously explored location, develops in infancy or early in childhood (Richards, 2003). Effortful forms of inhibitory control, involving the ability to stop performing automatic or routine behaviors when they become undesirable due to changing circumstances or to altered intentions, have the more protracted development (Band, van der Molen, Overtoom, & Verbaten, 2000; Harnishfeger & Pope, 1996; Houghton & Tipper, 1994; Pascual-Leone, 2001; Williams, Ponesse, Schachar, Logan, & Tannock, 1999). One form of effortful inhibition (Kipp, 2005) involves the maintenance of competing cognitive representations and the successive activation and suppression of irrelevant representations (Perner, Lang, & Kloo, 2002).

Suppression is that aspect of inhibitory control preventing no-longer-relevant information from remaining activated. Suppression is an active process, not simply a passive decay, and one that is driven by top-down semantic representations (Gernsbacher, 1995). Suppression uses mental resources; for example, the inhibition of inappropriate lexical interpretations puts demands on cognitive processes (Tompkins, Lehman-Blake, Baumgaertner, & Fassbinder, 2002).

Children with hydrocephalus, most with SBM, fail to suppress contextually irrelevant meaning, which is associated with poor text comprehension (Barnes et al., 2004), in agreement with the findings in adults that active suppression is important for both literal and figurative language comprehension (Gernsbacher & Faust, 1991; Gernsbacher & Robertson, 1999). Deficient suppression may not only preempt other comprehension processing resources, but also provide incomplete input to mental computations that generate a well-specific semantic representation (Tompkins et al., 2002). Children with SBM have poorly specified semantic representations that contain extraneous, contextually irrelevant information, which may explain the long-standing observation (Taylor, 1961) that their conversational language is referentially underspecified and tangential. The consequences of impaired semantic representation are considerable. Semantic representations may be well specified or underspecified, the latter form of shallow parsing being sufficient for some tasks, such as generating an index or chatting at a cocktail party, although not for others, such as providing or understanding specific instructions, communicating referentially detailed information, or academic learning (Sanford & Sturt, 2002).

CODA

Children exhibit a range of language disorders after acquired or congenital brain injury. Language breakdown may occur at the level of pragmatics, syntax, semantics, phonology, morphology, or speech production. While earlier views of language considered it in relative isolation, current views highlight how language is grounded in motor functions, is part of general-purpose cognitive systems, and relies on domain-general resources. Much is yet to be understood about the neurobiology of language disorders following CNS injury, but even more remains to be discovered about how language disorders engage with movement and cognition.

Acknowledgments

Preparation of this paper was supported in part by National Institute of Child Health and Human Development Grants P01 HD35946 and P01 HD35946–06, “Spina Bifida: Cognitive and Neurobiological Variability,” by National Institute of Neurological Diseases and Stroke Grant 2R01NS 21889–16, “Neurobehavioral Outcome of Head Injury in Children,” and by National Institutes of Health Grant 1RO1 HD04946, “Social Outcomes in Pediatric Traumatic Brain Injury.” I thank Arianna Stefanatos for assistance with manuscript preparation.

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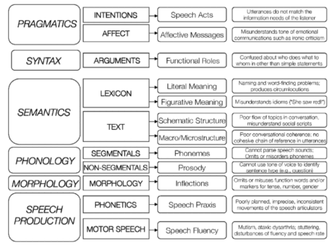

Figure 1.

Language taxonomy. The leftmost column shows levels of language representation. The next column shows functional domains within each representation level. The next column shows examples of each functional domain. The rightmost column provides examples of clinical deficits for each functional domain.